Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Estimation of settlement of ground using geogrid and deep mixing soil stabilization

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ABSTRACT: The settlement of ground using geogrid and deep mixing soil stabilization is estimated on the basis of the numerical analyses. From the results of analyses, the relationship between a stress share ratio and a stiffness of reinforcing material, an improvement percentage and a ratio of volumetric compression modulus of improved soil and untreated soil respectively is clarified. And the formulas to estimate the settlement of such ground are proposed and its validity is verified.

1 INTRODUCTION

The method using a geogrid reinforcement and a deep mixing soil stabilization as shown in Figure 1 is effective to reduce a differential settlement of ground (Ogisako 2000). However it is supposed that a settlement is not enough considered in its design. In this study a settlement of ground using geogrid and deep mixing soil stabilization which is arranged in the form of continuous wall is investigated on the basis of the numerical analyses and the formulas to estimate the settlement are proposed.

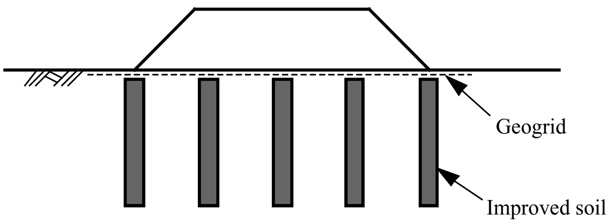


Figure 1. General idea of method using a geogrid reinforcement and a deep mixing soil stabilization.

2 ESTIMATION OF SETTLEMENT OF DEEP MIXING SOIL STABILIZED GROUND

2.1 *Method to estimate settlement*

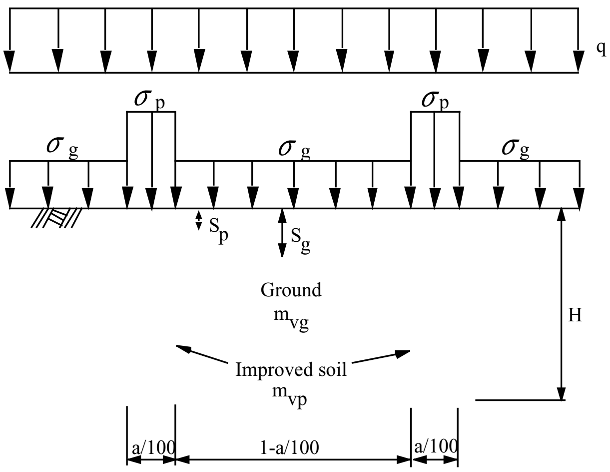
Supposing the case that an overburden load such as embankment is applied on the deep mixing soil stabilized ground, a stress and a deformation of improved soil and untreated soil are indicated as shown in Figure 2. Even if a uniform load is applied, a vertical stress acting on improved soil is different from that on untreated soil because of a difference of their stiffness. Due to the difference of acting stress, the differential settlement occurs. The settlements in this case are calculated by following equations respectively.

Settlement of untreated soil :

$$S_g = m_{vg} H \sigma_g \tag{1}$$

Settlement of improved soil :

$$S_p = m_{vp} H \sigma_p \quad \frac{m_{vg}}{n} H n_0 \sigma_g = \frac{n_0}{n} S_g \tag{2}$$



q : Overburden load
σ_p : Vertical stress acting on improved soil
σ_g : Vertical stress acting on untreated soil
S_p : Settlement generated at improved soil
S_g : Settlement generated at untreated soil
m_{vp} : Volumetric compression modulus of improved soil
m_{vg} : Volumetric compression modulus of untreated soil
a : Improvement percentage (%)

Figure 2. State of stress and displacement in deep mixing soil stabilized ground.

Differential settlement:

$$\Delta S = S_g - S_p = \left(1 - \frac{n_0}{n}\right) S_g = \left(1 - \frac{n_0}{n}\right) m_{vg} H \sigma_g \tag{3}$$

Where, m_{vg} : Volumetric compression modulus of untreated soil
m_{vp} : Volumetric compression modulus of improved soil
H : Thickness of ground

n_0 : Stress share ratio $= \dfrac{\sigma_p}{\sigma_g}$

n : Ratio of volumetric compression modulus of improved soil and untreated soil $\dfrac{m_{vg}}{m_{vp}}$

An overburden load is indicated as following.

$$q = \left(1 - \frac{a}{100}\right)\sigma_g + \frac{a}{100}\sigma_p = \left(1 - \frac{a}{100}\right)\sigma_g + \frac{a}{100} n_0 \sigma_g$$
$$= \left\{1 + \frac{a}{100}(n_0 - 1)\right\}\sigma_g \tag{4}$$

Where, a : Improvement percentage (%)

The differential settlement is indicated by following equation from equations (3) and (4).

$$\Delta S = \left(1 - \frac{n_0}{n}\right) \frac{m_{vg} H q}{\left\{1 + \frac{a}{100}(n_0 - 1)\right\}} \tag{5}$$

The parameters of H, q, a, m_{vg} and n in equation (5) are usually given from the results of soil experiment. Thus unknown parameter in equation (5) is a stress share ratio, n_0, only. It is supposed that a stress share ratio is dependent on an improvement percentage and a ratio of volumetric compression modulus of improved soil and untreated soil. Therefore it is very important to presume a stress share ratio precisely in estimating a settlement of deep mixing soil stabilized ground.

2.2 *Presumption of stress share ratio*

In this study numerical analyses by finite element method are performed to presume a stress share ratio (Ogisako 2001). The parameters of an improvement percentage and a ratio of volumetric compression modulus of improved soil and untreated soil are varied in analyses because a stress share ratio is dependent on them as mentioned above. An example of analytical models is shown in Figure 3 in which a load of 49 kN/m^2 is applied on a soft ground 10m in thickness and a width of improved soil is 1m. In analysis plane strain condition is assumed and a thin layer whose young's modulus equals to 1/100 of ground's is set between improved soil and ground in order to consider discontinuity.

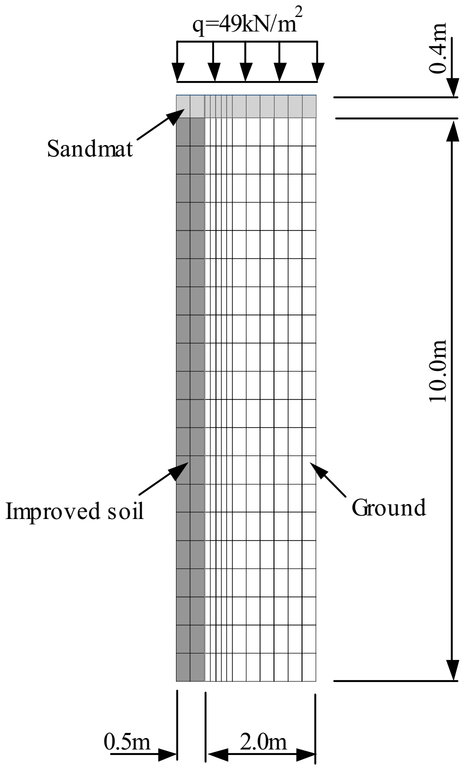


Figure 3. Analytical model of deep mixing soil stabilized ground in the case that improvement percentage is 20%.

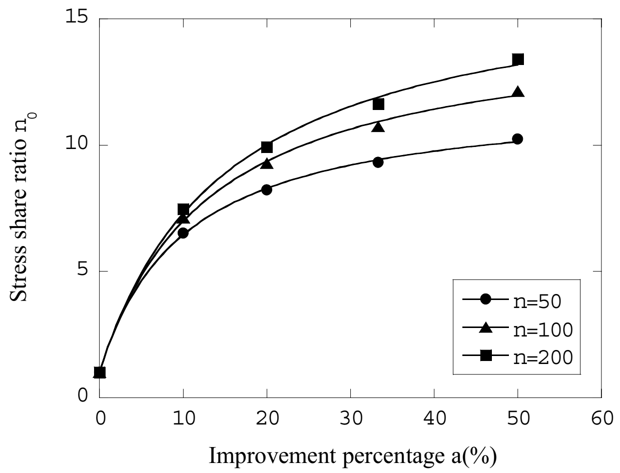


Figure 4. Relationship between stress share ratio and improvement percentage in deep mixing soil stabilized ground.

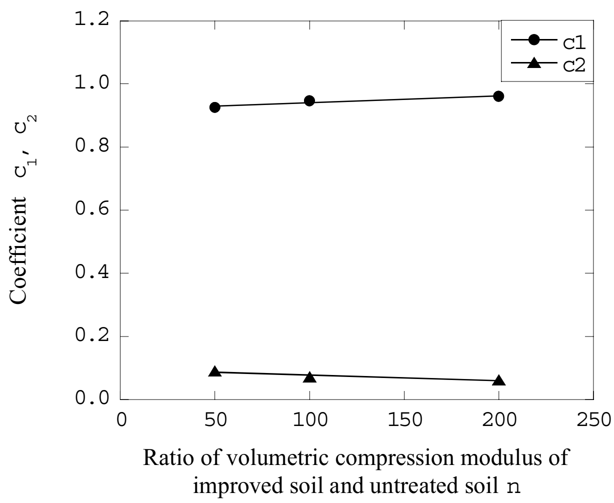


Figure 5. Relationship between coefficients c_1, c_2 in formula (6) and ratio of volumetric compression modulus.

The stress share ratio obtained from analytical results is plotted against improvement percentage as shown in Figure 4. The stress share ratio increases as an improvement percentage increases. The stress share ratio becomes larger as a ratio of volumetric compression modulus of improved soil and untreated soil becomes larger. This relationship between stress share ratio and improvement percentage is closely resembled by a hyperbola shown as solid lines in Figure 4. Its formula is presented as following.

$$n_0 = \frac{a}{c_1 + c_2 a} + 1 \tag{6}$$

Where, a : improvement percentage (%)

Although coefficients c_1 and c_2 vary with value of n, the relationship between c_1 ,c_2 and n is closely resembled linearly as shown in Figure 5 and presented as following.

$$c_1 = 0.92 + 0.00022n \tag{7}$$

$$c_2 = 0.096 - 0.00017n \tag{8}$$

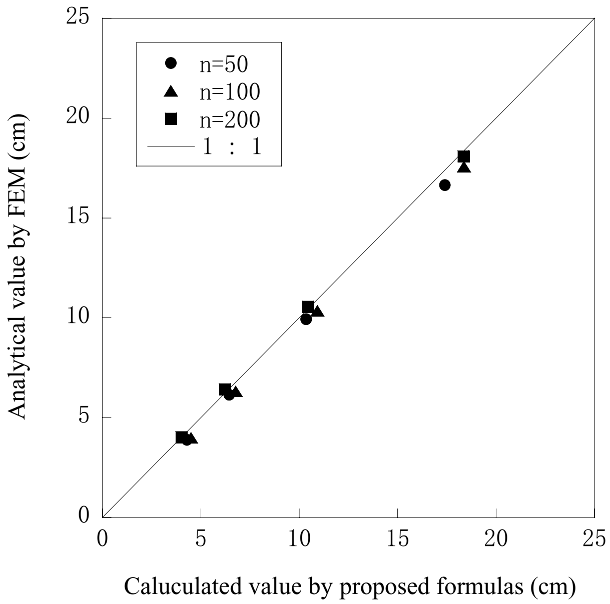


Figure 6. Comparison of differential settlement of deep mixing soil stabilized ground.

Accordingly stress share ratio can be calculated for any improvement percentage and ratio of volumetric compression modulus by formulas (6) to (8). Further differential settlement can be estimated by substituting calculated stress share ratio into formula (5).

Figure 6 shows the comparison between calculated values of differential settlement by formulas (5) to (8) and analytical values of it by finite element method in the same condition. The calculated values by proposed formulas agree well with the analytical values by finite element method. Thus it is proved that the proposed formulas can estimate a differential settlement of deep mixing soil stabilized ground precisely.

3 ESTIMATION OF SETTLEMENT OF GROUND USING GEOGRID AND DEEP MIXING SOIL STABILIZATION

3.1 *Method to estimate settlement*

The differential settlement is indicated as following on the basis of point of view in section 2.

$$\Delta S_r = \left(1 - \frac{n_r}{n}\right) \frac{m_{vg} H q}{\left\{1 + \frac{a}{100} n_r - 1\right\}} \tag{9}$$

Where, ΔS_r : Differential settlement in ground using geogrid and deep mixing soil stabilization

n_r : Stress share ratio in ground using geogrid and deep mixing soil stabilization

The differential settlement of ground using geogrid and deep mixing soil stabilization can be calculated from formula (9) by presuming stress share ratio, n_r.

3.2 *Presumption of stress share ratio*

Numerical analyses by finite element method are performed to presume a stress share ratio in ground using geogrid and deep mixing soil stabilization (Ogisako 2001). It is supposed that a stress share ratio in such ground is dependent on not only an improvement percentage and a ratio of volumetric compression modulus of improved soil and untreated soil but also a stiffness of geogrid reinforcement. Thus these parameters vary in analyses as shown in table 1. An example of analytical models is shown in Figure 7 in which a load of 49 kN/m^2 is applied on a soft ground 10m in thickness and a width of improved soil is 1m as well as the case of deep mixing soil stabilized ground. In analysis plane strain condition is assumed and a geogrid reinforcement is represented by a plane truss element which transmits only an axial force and a thin layer whose young's modulus equals to 1/100 of ground's is set between improved soil and ground in order to consider discontinuity.

Table 1. Analytical cases of ground using geogrid and deep mixing soil stabilization.

Case	Young's modulus of untreated soil Eg (MPa)	Young's modulus of improved soil Ep (MPa)	Improvement percentage a (%)	Stiffness of reinforcement Er (kN/m)
1-12	0.98	49	10	98
13-24				490
25-36		98	20	981
37-48				1961
49-60		196	33	3923
61-72			50	6865
73-84				9807

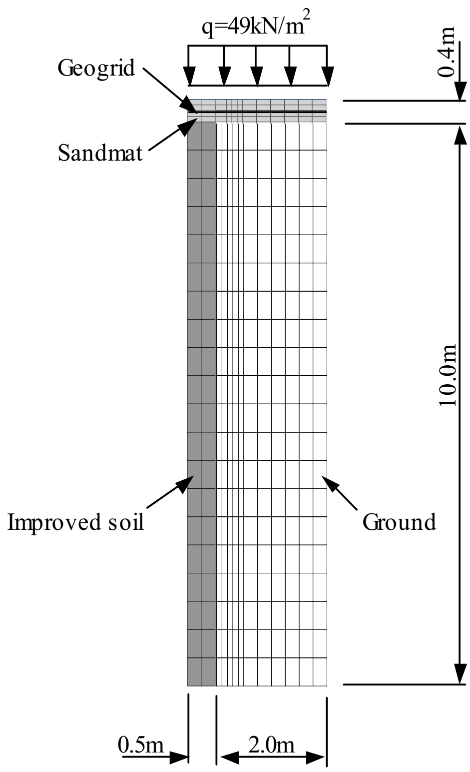


Figure 7. Analytical model of ground using geogrid and deep mixing soil stabilization in the case that improvement percentage is 20%.

Figure 8 shows the relationship between stress share ratio and improvement percentage in the case that a ratio of volumetric compression modulus of improved soil and untreated soil, n, equals to 50 and a stiffness of reinforcement, E_r, equals to 981 kN/m. In this figure the case of deep mixing soil stabilization only also is shown. The stress share ratio increases as an improvement percentage increases and it is larger than that of deep mixing soil stabilization only. Thus a ratio of stress share ratio of the case with reinforcement to that without reinforcement is plotted against a stiffness of reinforcement as shown in Figure 9.

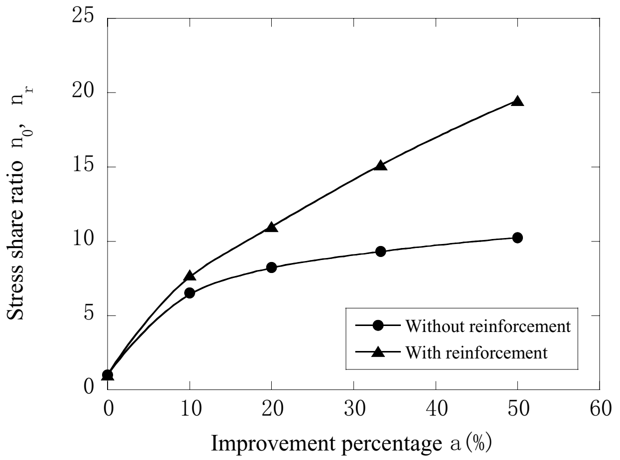


Figure 8. Relationship between stress share ratio and improvement percentage in the case that n=50 and E_r=981 kN/m.

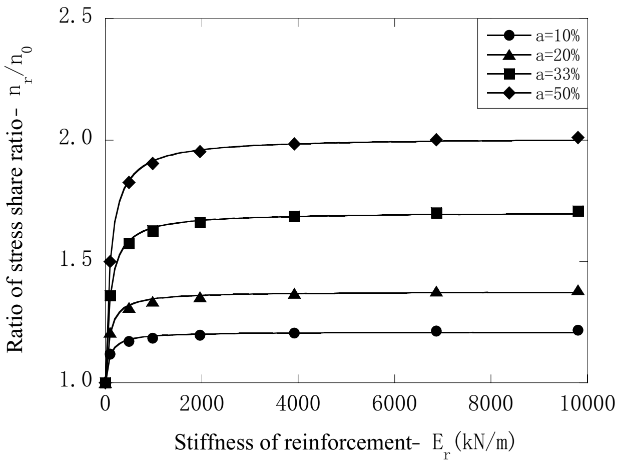


Figure 9. Relationship between ratio of stress share ratio, n_r/n_0, and stiffness of reinforcement in the case that n=50.

A ratio of both stress share ratio, n_r/n_0, is larger as improvement percentage is large and it becomes larger as a stiffness of reinforcement increases but tends to converse a constant value. The relationship between a ratio of stress share ratio, n_r/n_0, and a stiffness of reinforcement is closely resembled by a hyperbola shown as solid lines in Figure 9. Its formula is presented as following.

$$\frac{n_r}{n_0} = \frac{E_r}{c_3 \quad c_4 E_r} + 1 \tag{10}$$

Where, E_r : Stiffness of reinforcement

It is supposed that coefficients c_3 and c_4 in formula (10) are dependent on an improvement percentage and a ratio of volumetric compression modulus of improved soil and untreated soil. Thus these coefficients c_3 and c_4 are plotted against improvement percentage, a, for each ratio of volumetric compression modulus of improved soil and untreated soil, n, as shown in Figure 10 and Figure 11. The relationship between coefficients c_3 and c_4 and improvement percentage is closely resembled by a hyperbola shown as solid lines in these figures. Their formulas are presented as following.

$$c_3 = \frac{c_{31}}{c_{32} \quad a} + c_{33} \tag{11}$$

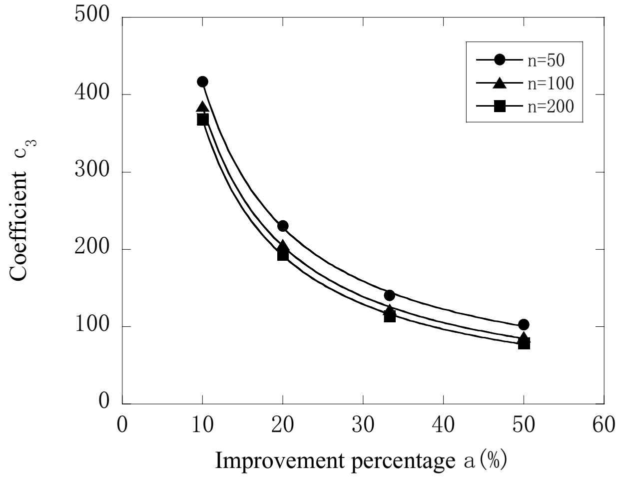


Figure 10. Relationship between coefficients c_3 in formula (10) and improvement percentage.

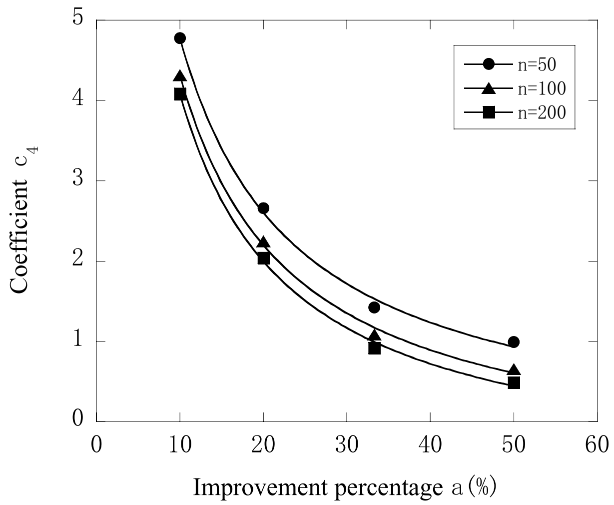


Figure 11. Relationship between coefficients c_4 in formula (10) and improvement percentage.

$$c_4 = \frac{c_{41}}{c_{42} \quad a} + c_{43} \tag{12}$$

Further coefficients c_{31}- c_{33} in formula (11) and c_{41}- c_{43} in formula (12) are dependent on a ratio of volumetric compression modulus of improved soil and untreated soil, n, and the relationship between these coefficients and n is closely resembled linearly as following formulas.

$$c_{31} = 4867 - 4.00n \tag{13}$$

$$c_{32} = 1.75 - 0.0037n \tag{14}$$

$$c_{33} = 10.34 - 0.073n \tag{15}$$

$$c_{41} = 72.33 - 0.045n \tag{16}$$

$$c_{42} = 3.84 - 0.0036n \tag{17}$$

$$c_{43} = 0.33 - 0.0023n \tag{18}$$

Accordingly a ratio of stress share ratio, n_r/n_0, can be calculated for any stiffness of reinforcement, improvement percentage

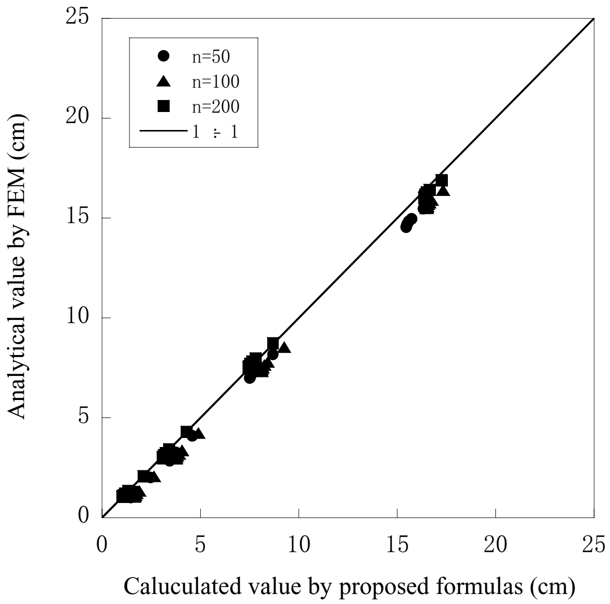


Figure 12. Comparison of differential settlement of ground using geogrid and deep mixing soil stabilization.

and ratio of volumetric compression modulus by formulas (10) to (18). Thus a stress share ratio of the case with reinforcement, n_r, can be calculated from this n_r/ n_0 and a stress share ratio of the case without reinforcement, n_0, obtained from formulas (6) to (8). Further differential settlement can be estimated by substituting calculated stress share ratio, n_r, into formula (9).

Figure 12 shows the comparison between calculated values of differential settlement by formulas (6) to (18) and analytical values of it by finite element method in the same condition. The calculated values by proposed formulas agree well with the analytical values by finite element method. Thus it is proved that the proposed formulas can estimate a differential settlement of ground using geogrid and deep mixing soil stabilization precisely.

4 ESTIMATION OF REINFORCEMENT TENSILE FORCE

When overburden load, q, acts on the ground using geogrid and deep mixing soil stabilization, tensile force of reinforcement bears a part of overburden load as shown in Figure 13. Here a rate of load that tensile force of reinforcement bears against total load between improved soils is defined as α.

$$\alpha = \frac{2T}{ql} \tag{19}$$

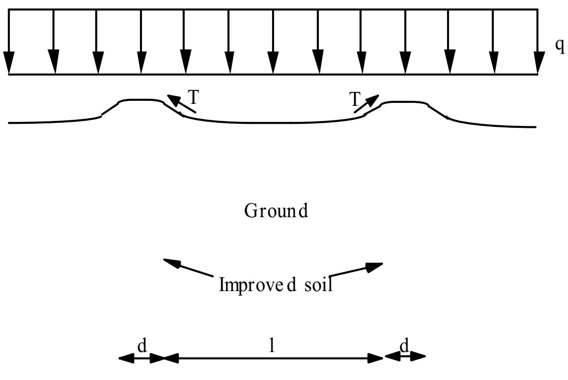


Figure 13. General idea of tensile force of reinforcement

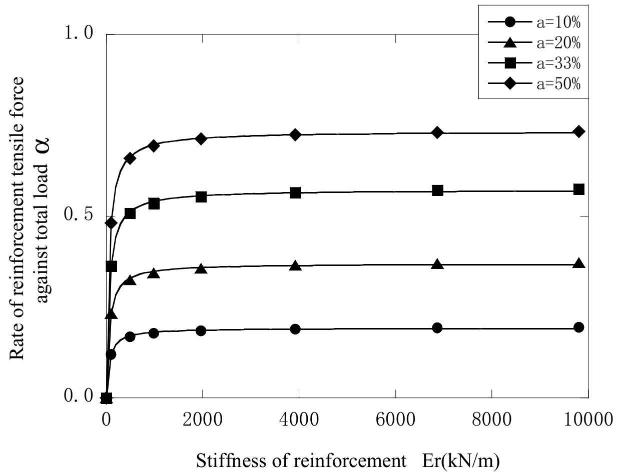


Figure 14. Relationship between rate of reinforcement tensile force against total load, α, and stiffness of reinforcement in the case that n=50.

Where, T : Tensile force of reinforcement
q : Overburden load
l : Distance between improved soils

α calculated by formula (19) using tensile force of reinforcement obtained from analytical results of finite element method in section 3 is plotted against stiffness of reinforcement as shown in Figure 14. α is larger as improvement percentage is large and it becomes larger as a stiffness of reinforcement increases but tends to converse a constant value. The relationship between α and a stiffness of reinforcement is closely resembled by a hyperbola shown as solid lines in Figure 14. Its formula is presented as following.

$$\alpha = \frac{E_r}{c_5 \quad c_6 E_r} \tag{20}$$

It is supposed that coefficients c_5 and c_6 in formula (20) are dependent on an improvement percentage and a ratio of volumetric compression modulus of improved soil and untreated soil. Thus these coefficients c_5 and c_6 are plotted against improvement percentage, a, for each ratio of volumetric compression modulus of improved soil and untreated soil, n, as shown in Figure15 and Figure 16. The relationship between coefficients c_5 and c_6 and improvement percentage is closely resembled by a hyperbola shown as solid lines in these figures. Their formulas are presented as following.

$$c_5 = \frac{c_{51}}{c_{52} \quad a} + c_{53} \tag{21}$$

$$c_6 = \frac{c_{61}}{c_{62} \quad a} + c_{63} \tag{22}$$

Further coefficients c_{51}- c_{53} in formula (21) and c_{61}- c_{63} in formula (22) are dependent on a ratio of volumetric compression modulus of improved soil and untreated soil, n, and the relationship between these coefficients and n is closely resembled linearly as following formulas.

$$c_{51} = 2982 - 1.26n \tag{23}$$

$$c_{52} = \quad 0.53 + 0.00098n \tag{24}$$

$$c_{53} = 11.32 + 0.0098n \tag{25}$$

$$c_{61} = 41.42 - 0.024n \tag{26}$$

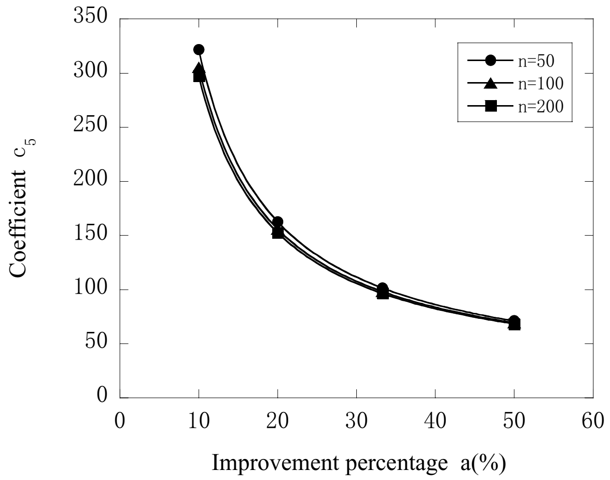


Figure 15. Relationship between coefficients c_5 in formula (20) and improvement percentage.

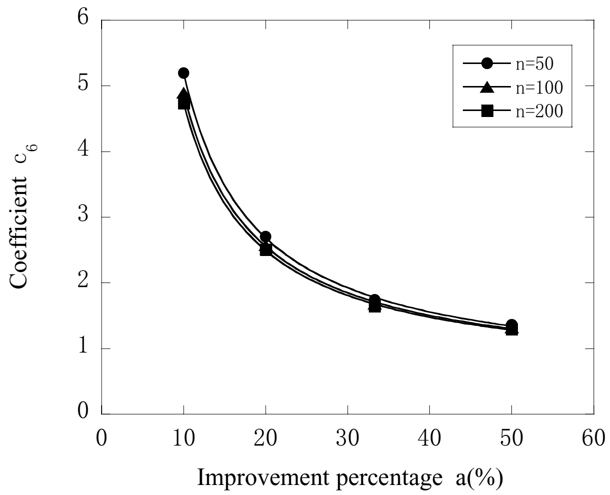


Figure 16. Relationship between coefficients c_6 in formula (20) and improvement percentage.

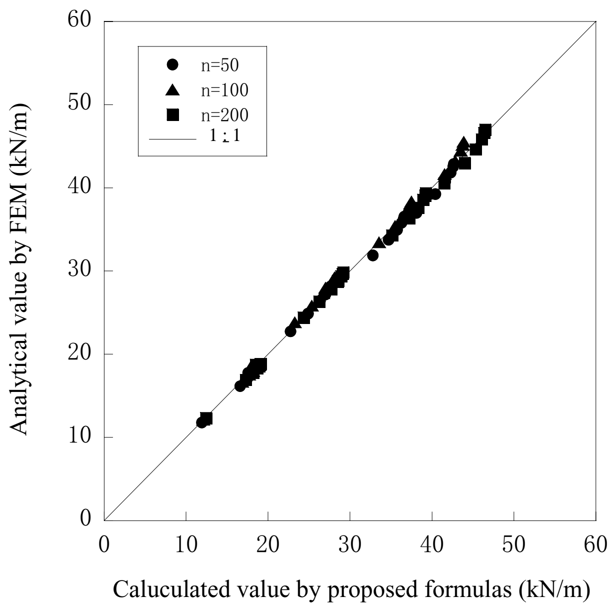


Figure 17. Comparison of reinforcement tensile force.

$$c_{62} = -1.33 + 0.00042n \quad (27)$$

$$c_{63} = 0.50 + 0.00013n \quad (28)$$

Accordingly α can be calculated for any stiffness of reinforcement, improvement percentage and ratio of volumetric compression modulus by formulas (20) to (28). Further tensile force of reinforcement can be estimated by substituting calculated α into formula (19).

Figure 17 shows the comparison between calculated values of reinforcement tensile force by formulas (19) to (28) and analytical values of it by finite element method in the same condition. The calculated values by proposed formulas agree well with the analytical values by finite element method. Thus it is proved that the proposed formulas can estimate a reinforcement tensile force in ground using geogrid and deep mixing soil stabilization precisely.

5 CONCLUSIONS

The behavior of ground using geogrid reinforcement and deep mixing soil stabilization which is arranged in the form of continuous wall is investigated on the basis of numerical analyses. The following is concluded.

(1) The stress share ratio that is necessary to calculate settlement of deep mixing soil stabilized ground is estimated by FEM analyses. It is made clear that relationship between stress share ratio and improvement percentage can be closely resembled by a hyperbola. From this relationship the formulas presuming stress share ratio are proposed. The calculated values by proposed formulas agree well with the analytical values by finite element method. Thus it is proved that the proposed formulas can estimate a differential settlement of deep mixing soil stabilized ground precisely.

(2) The stress share ratio of ground using geogrid and deep mixing soil stabilization is estimated by FEM analyses. It is made clear that stress share ratio with reinforcement, n_r, is larger than that without reinforcement, n_0, and relationship between ratio of them, n_r/n_0, and stiffness of reinforcement can be closely resembled by a hyperbola. From this relationship the formulas presuming stress share ratio are proposed. The calculated values by proposed formulas agree well with the analytical values by finite element method. Thus it is proved that the proposed formulas can estimate a differential settlement of ground using geogrid and deep mixing soil stabilization precisely.

(3) From the analytical results the formulas presuming reinforcement tensile force are proposed. The calculated values by proposed formulas agree well with the analytical values by finite element method. Thus it is proved that the proposed formulas can estimate a reinforcement tensile force in ground using geogrid and deep mixing soil stabilization precisely.

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